Self-benchmarking Guide for Cleanrooms: Metrics, Benchmarks, Actions

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Acknowledgements

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1. Introduction

Purpose

This guide describes energy efficiency metrics and benchmarks that can be used to track the performance of and identify potential opportunities to reduce energy use in cleanrooms.

Target audience

This guide is primarily intended for personnel who have responsibility for managing energy use in existing facilities – including facilities managers, energy managers, and their engineering consultants. Additionally, cleanroom planners and designers may also use the metrics and benchmarks described in this guide for goal-setting in new construction or major renovation.

What this guide does

This guide provides the following information:

- A step-by-step outline of the benchmarking process.
- A set of performance metrics for the whole building as well as individual systems. For each metric, the guide provides a definition, performance benchmarks, and potential actions that can be inferred from evaluating this metric.
- A list and descriptions of the data required for computing the metrics

This guide is complemented by spreadsheet templates for data collection and for computing the benchmarking metrics.

This guide builds on prior cleanroom benchmarking studies supported by the California energy Commission. Much of the benchmarking data are drawn from the LBNL cleanroom benchmarking database that was developed from these studies. Additional benchmark data were obtained from engineering experts including facility designers and energy managers.

What this guide does not do

While the energy benchmarking approach describe in this guide can be used to identify potential efficiency opportunities, this guide does not in and of itself constitute an energy audit procedure or checklist. (However, benchmarking may be used as part of an energy audit procedure, or to help prioritize areas for more in-depth audits). The guide does not describe how to calculate savings from the potential actions identified. This guide also does not describe detailed measurement procedures and equipment needed for obtaining the data required to compute metrics.

Structure of this guide

Section 2 outlines the benchmarking process and how to use this guide in this context. Users should start here.

Sections 3 through 7 describe the performance metrics and how to use them. A summary of the metrics is provides at the beginning of each section. Users can use these sections as a reference manual, to prioritize which metrics to evaluate, and determine data requirements.

Section 8 provides a list of the data required for computing the metrics and limited guidance on how to obtain the data.

Section 9 lists references.

Definitions

A **Performance Metric** is a unit of measure used to assess performance; e.g. Ventilation airflow efficiency (W/cfm).

A **Performance Benchmark** is a particular value of the metric that is used as a point of comparison; e.g. 0.4 W/cfm may be “good practice” benchmark for ventilation airflow efficiency.

2. Benchmarking Process

Set benchmarking goals

- *Identify purpose of benchmarking – baselining, identifying actions, comparison to portfolio, etc.*
- *Determine extent of facility and systems to be evaluated.*

Prioritize metrics

- *Use metrics/data template*
- *Prioritize based on goals and available resources*

Identify required data and develop data collection plan

- *Use metrics/data template*
- *Identify source (EMCS, drawings, temporary meters, etc.), measurement period and frequency, responsible person for each data item.*

Obtain and install monitoring equipment

- *Utility lending libraries may be good source for monitoring equipment.*

Collect data

- *Check equipment and ensure that data is being collected as intended.*

Analyze data and compute metrics

- *Use spreadsheets and metrics/data template to convert raw data into metrics.*

Benchmark metrics and identify potential actions

- *Compare metrics to benchmark values provided in this guide. Identify potential actions based on benchmark results.*

Create follow-up action plan

- *Identify which actions can be implemented immediately and which require more detailed audit.*

Share results

- *Share and compare results with peer organizations.*
- *Add results to benchmarking databases.*

Note regarding metrics for overall facility energy intensity:

Facility-level energy use metrics (such as BTU/sf and W/sf) are the most common means to compare the overall energy intensity of a facility. However, such metrics are typically not effective for comparing cleanrooms, because: a) most cleanrooms are part of much larger research or manufacturing facilities; and b) even if energy use for the cleanroom could be determined, there are no established means to normalize for process energy use, which can vary significantly in type and intensity across different cleanrooms.

Therefore, the list of metrics below does not include facility level metrics. Rather, the metrics are focused on system efficiency. Users who wish to compute facility level metrics may refer to the laboratory benchmarking guide.

3. Cleanroom Environmental Condition Metrics

ID	Name	Priority
C1	Temperature Range	2
C2	Humidity Range	1
C3	Pressurization	1

C1: Temperature Range

Description:

This metric describes the operating (measured) range of temperature in the cleanroom. The measured temperatures can also be compared to the intended (setpoint) temperature.

Benchmarks:

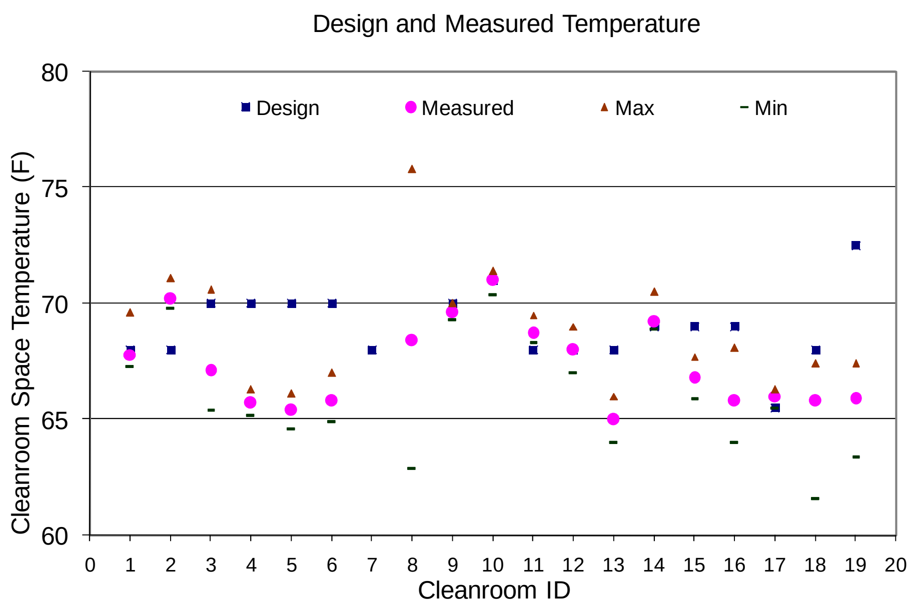

Figure 1. Design and measured temperature ranges for cleanrooms in the LBNL database

Actions Inferred:

- Maintaining temperature within a tight tolerance usually results in increased energy use due to reheat. Allowing a wider temperature range can reduce energy use.

C2: Humidity Range

Description:

This metric describes the measured (operating) range of humidity in the cleanroom. The measured values can also be compared to the intended (setpoint) humidity.

Benchmarks:

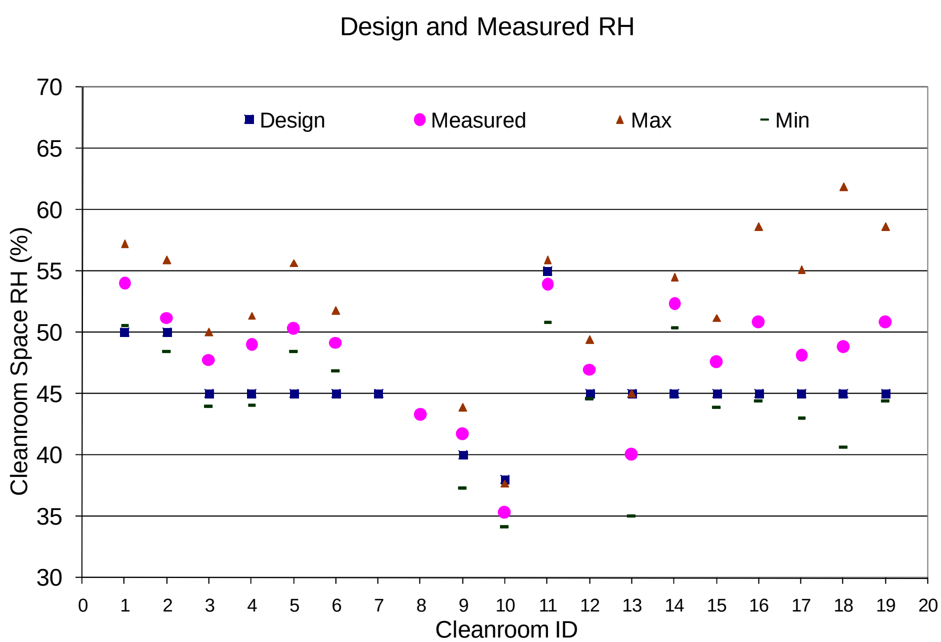

Figure 2. Humidity ranges for cleanrooms in the LBNL database

Actions Inferred:

- Maintaining humidity within a tight tolerance usually results in increased energy use due to reheat. Allowing a wider humidity range can reduce energy use.

C3: Pressurization

Description:

This metric describes the pressure differential between the cleanroom and the surrounding spaces.

Benchmarks:

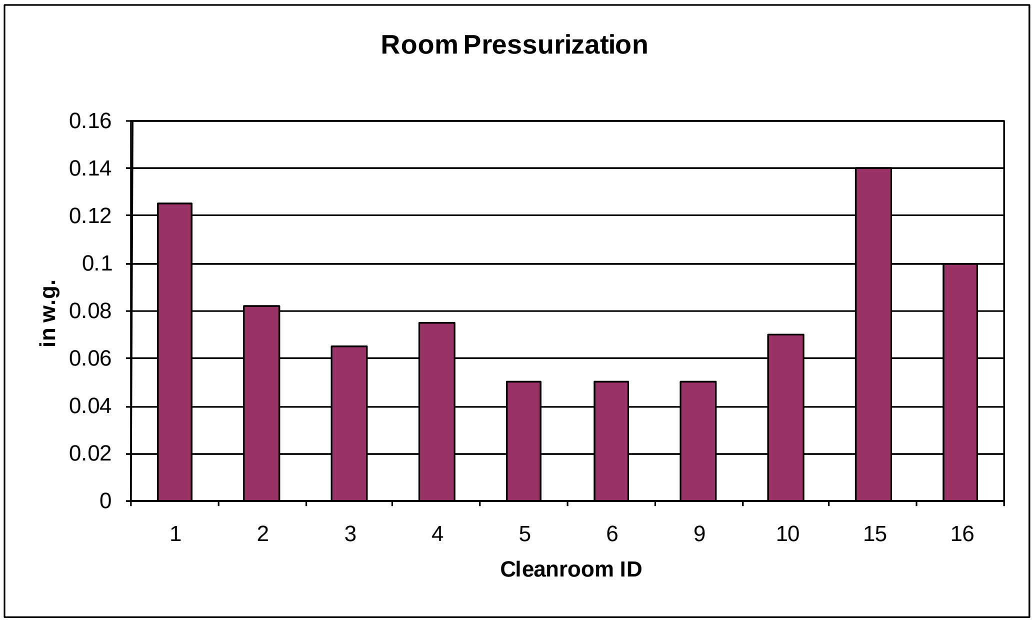

Figure 3. Pressurization levels for cleanrooms in the LBNL database

Actions Inferred:

- Optimize the differential pressure to the minimum required to meet cleanliness requirements. Excessive pressurization increases energy use.

4. Ventilation System Metrics

ID	Name	Priority
V1	Air Change Rate	1
V2	RCU Airflow Efficiency	1
V3	RCU Total System Pressure Drop	1
V4	RCU Filter Pressure Drop	1
V5	MAU Air Handling Airflow Efficiency	1
V6	MAU Total System Pressure Drop	1
V7	MAU Filter Pressure Drop	1
V8	Exhaust Air Handling Airflow Efficiency	1

V1: Air Change Rate

Description:

This metric is the minimum amount of outside air expressed in air changes per hour.

Units: ACH [hr^{-1}]

V1 = dV2*60 ÷ dG2

where:

dV2: RCU Airflow [cfm]

dG2: Cleanroom Volume [net ft^3]

See section 8 for more information on the data items.

Benchmarks:

Figures 4-6 show the air change rates in for various classes of cleanrooms in the LBNL cleanroom database.

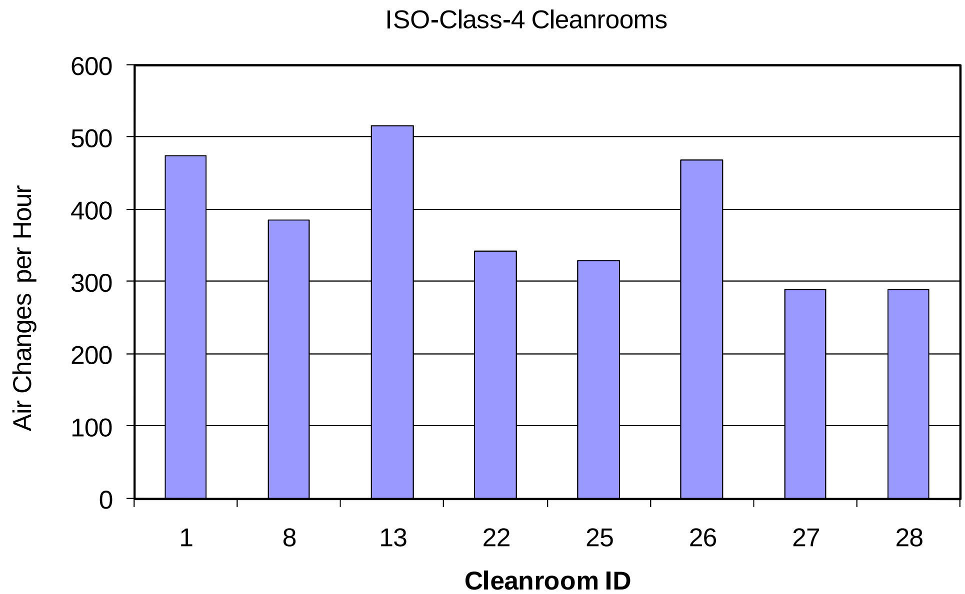

Figure 4. Air change rates in for various ISO-Class-4 cleanrooms in the LBNL cleanroom database. ISO-Class-4 is equivalent to class 10 in FS 209.

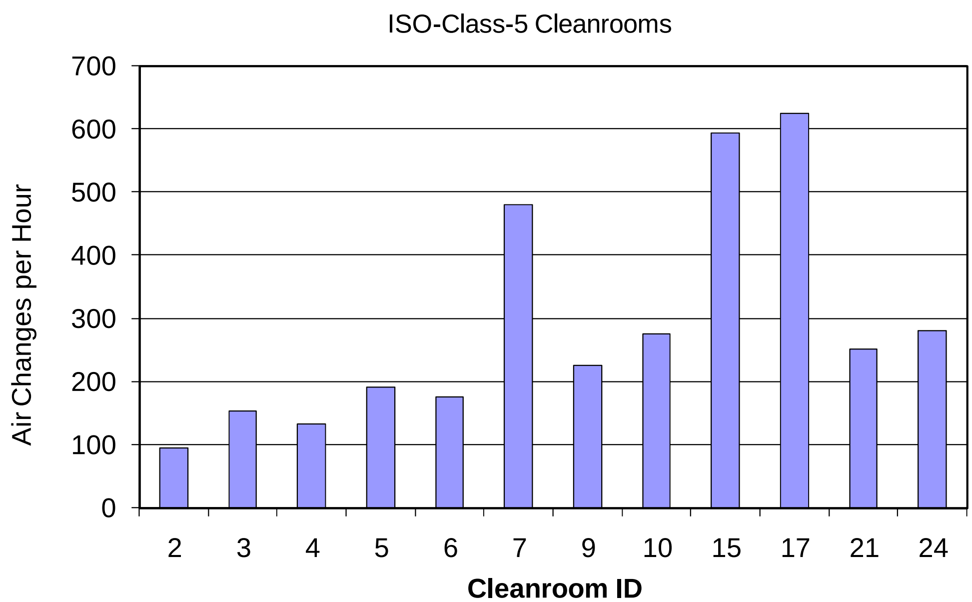

Figure 5. Air change rates in for various ISO-Class-5 cleanrooms in the LBNL cleanroom database. ISO-Class-5 is equivalent to class 100 in FS 209.

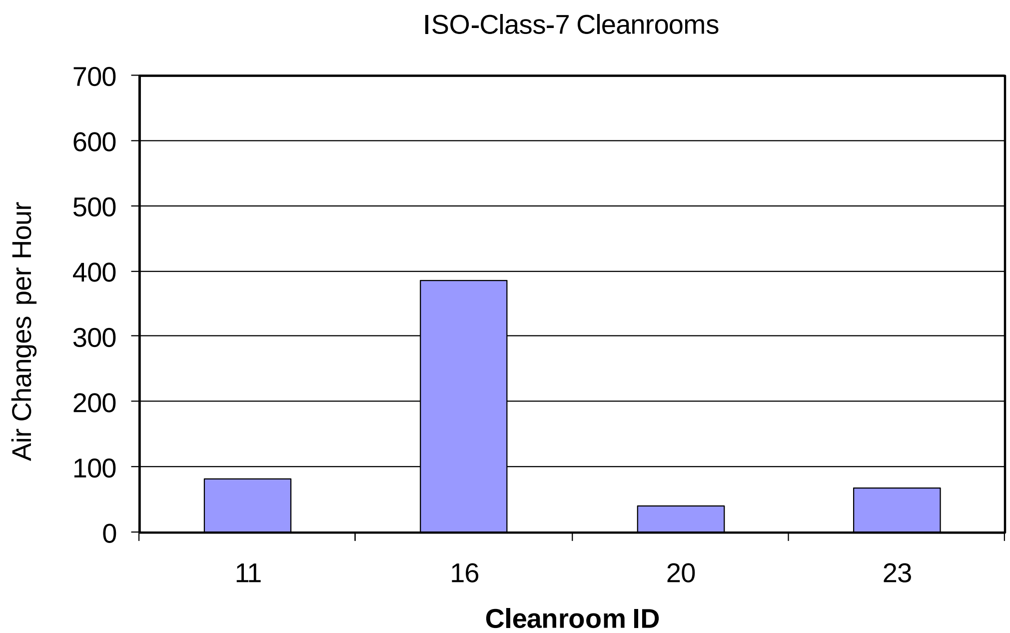

Figure 6. Air change rates in for various ISO-Class-7 cleanrooms in the LBNL cleanroom database. ISO-Class-7 is equivalent to class 10000 in FS 209.

Actions Inferred:

Air change rates should be optimized to meet the cleanliness level and should not be higher than necessary. The benchmark data for the LBNL database show that air change rates vary significantly across different cleanrooms in the same cleanliness class. Demand-controlled ventilation (i.e. modulating air change based on monitoring particle count) is one way to optimize the air change rates.

V2: RCU Airflow Efficiency

Description:

This metric characterizes overall airflow efficiency of the recirculating air unit in terms of the total fan power required per unit of airflow. It provides an overall measure of how efficiently air is moved through the cleanroom.

Units: W/cfm [$W/l\text{-}s^{-1}$]

V2 = dV1*1000 ÷ dV2
where:
dV1: RCU Power (kW)
dV2: RCU Airflow (cfm)

See section 8 for more information on the data items.

Benchmarks:

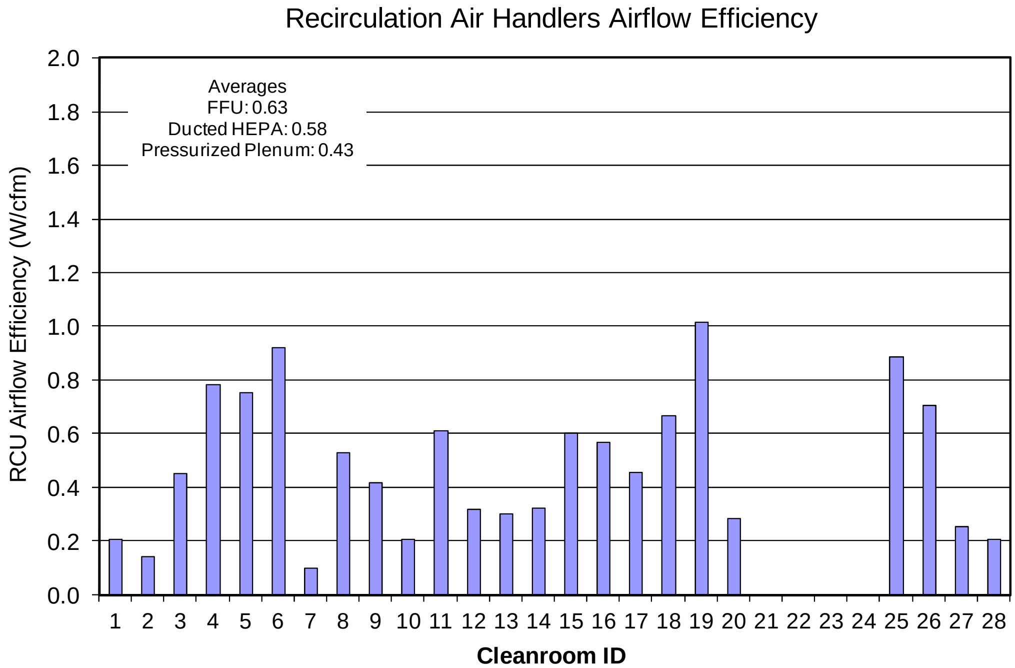

Figure 7. Airflow efficiency for a set of cleanrooms in the LBNL database

Actions Inferred:

There are two major actions that can be taken to improve airflow efficiency:

- Reduce system pressure drop by removing or changing components (e.g. excessive/dirty filters).
- Improve fan system efficiency by retrofitting motors, belts, drives.

V3: RCU Total System Pressure Drop

Description:

This metric is the total pressure drop across the recirculation air handling units – the sum of the supply side pressure drop (from fan to room) and return side pressure drop (from room to fan). It is a key determinant of overall airflow efficiency.

Units: in. w.g [Pa]

V3 = dV3
where:
dV3: RCU Total Pressure Drop (in. w.g.)

See section 8 for more information on the data items.

Benchmarks:

The LBNL cleanroom database does not currently have any data for this metric.

Actions Inferred:

- Remove or change components (e.g. excessive/dirty filters, excessive sound attenuators).
- In new construction or major retrofit, select air distribution systems with low pressure drop (e.g. pressurized plenum)

V4: RCU Filter Pressure Drop

Description:

This metric is the pressure drop across the filters in the recirculating air unit.

Units: in. w.g [Pa]

V4 = dV4
where:
dV3: RCU Filter Pressure Drop (in. w.g.)

See section 8 for more information on the data items.

Benchmarks:

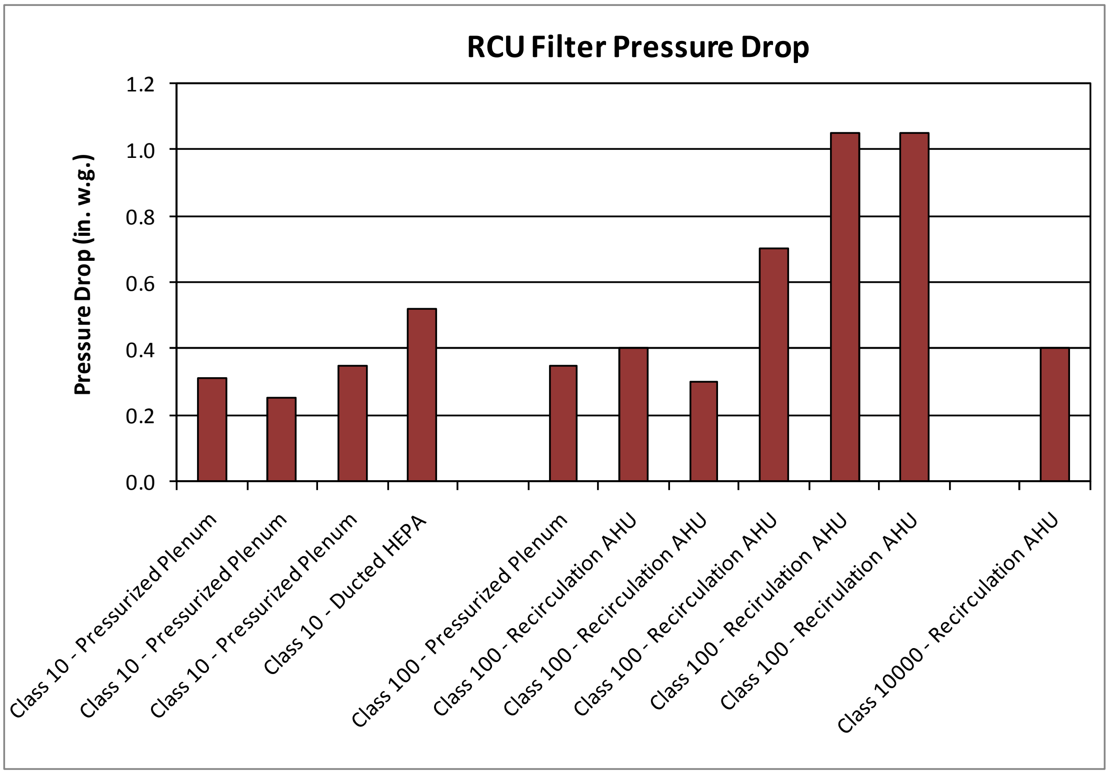

Figure 8. RCU filter pressure drop for cleanroom RCUs in the LBNL database.

Actions Inferred:

- Use low pressure drop filters

Special Considerations:

A high filter pressure drop does not necessarily indicate an efficiency opportunity, since filter pressure drop is also a function of factors such as the airflow configuration, floor tile configuration, etc.

V5: MAU Airflow Efficiency

Description:

This metric characterizes overall airflow efficiency of the make-up air unit in terms of the total fan power required per unit of airflow. It provides an overall measure of how efficiently air is moved through the make-up air unit.

Units: W/cfm [$W/l\text{-}s^{-1}$]

V5 = dV5*1000 ÷ dV6
where:
dV5: MAU Power (kW)
dV6: MAU Airflow (cfm)

See section 8 for more information on the data items.

Benchmarks:

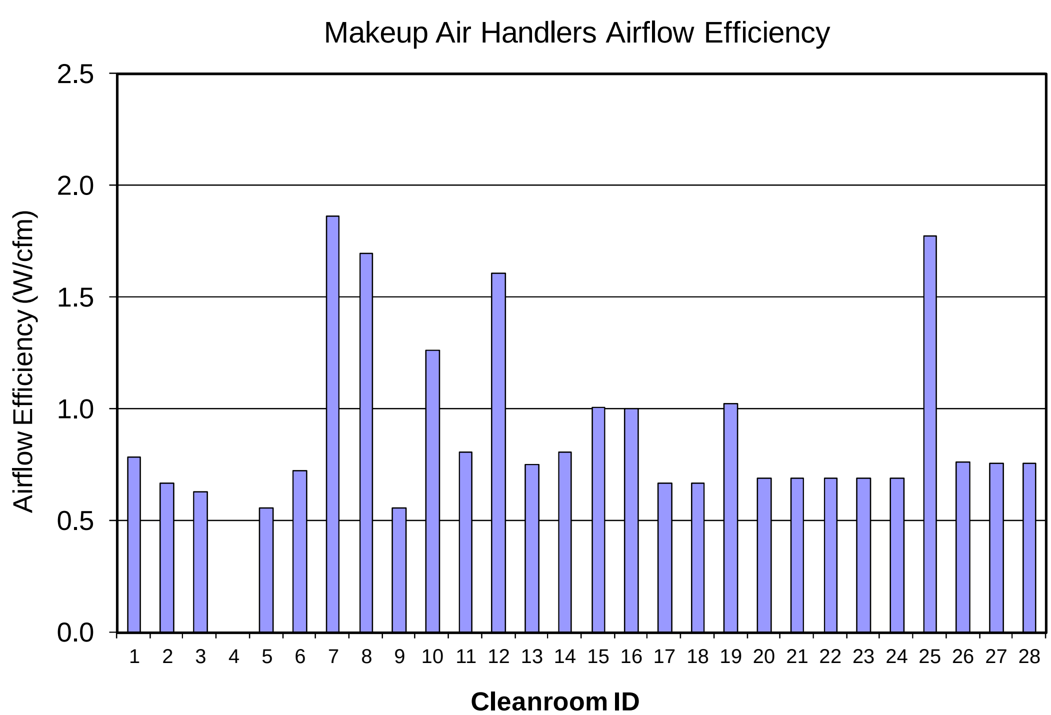

Figure 9. MAU airflow efficiency for cleanrooms in the LBNL database

Actions Inferred:

There are two major actions that can be taken to improve airflow efficiency:

- Reduce system pressure drop by removing or changing components (e.g. excessive/dirty filters).
- Improve fan system efficiency by retrofitting motors, belts, drives.

V6: MAU Total System Pressure Drop

Description:

This metric is the total pressure drop across the make-up air handling units. It is a key determinant of overall airflow efficiency.

Units: in. w.g [Pa]

V6 = dV7
where:
dV7: MAU Total Pressure Drop (in. w.g.)

See section 8 for more information on the data items.

Benchmarks:

The LBNL cleanroom database does not currently have any data for this metric.

Actions Inferred:

- Remove or change components (e.g. excessive/dirty filters, excessive sound attenuators).
- In new construction or major retrofit, select air distribution configuration with low pressure drop (e.g. minimize bends)

V7: MAU Filter Pressure Drop

Description:

This metric is the pressure drop across the filters in the make-up air unit.

Units: in. w.g [Pa]

V7 = dV8
where:
dV8: MAU Filter Pressure Drop (in. w.g.)

See section 8 for more information on the data items.

Benchmarks:

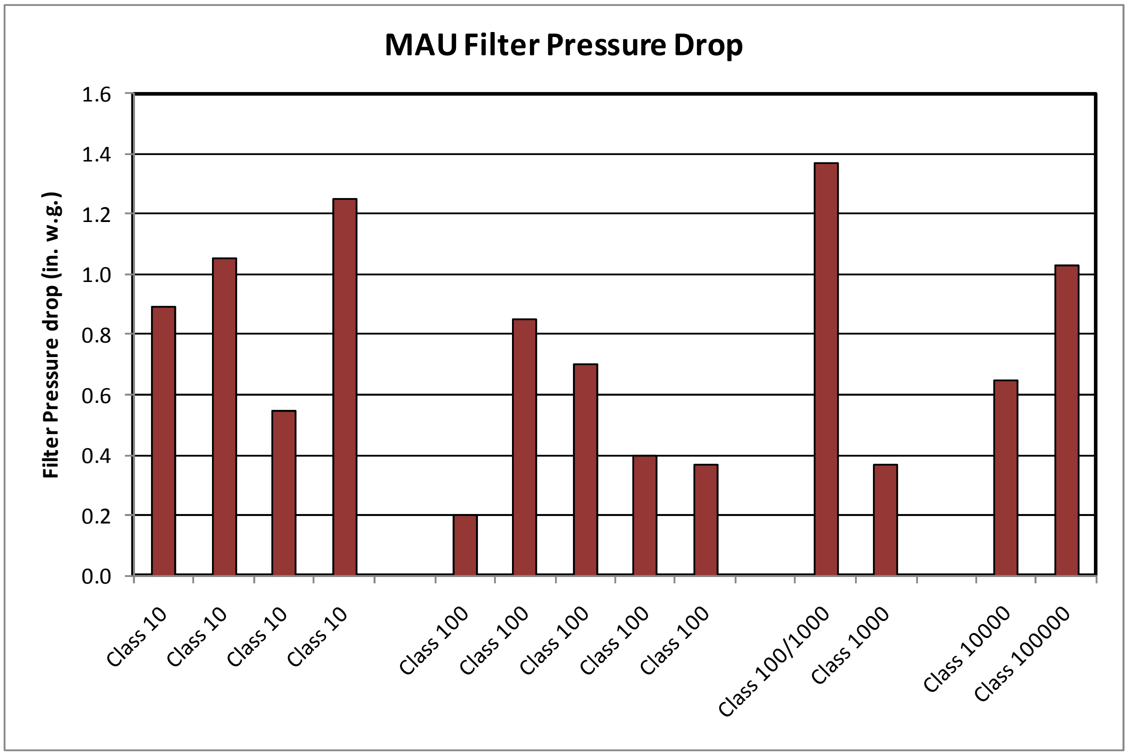

Figure 10. MAU filter pressure drop for cleanroom MAUs in the LBNL database.

Actions Inferred:

- Use low pressure drop filters

Special Considerations:

A high filter pressure drop does not necessarily indicate an efficiency opportunity, since filter pressure drop is also a function of factors such as the airflow configuration, floor tile configuration, etc.

V8: Exhaust Airflow Efficiency

Description:

This metric characterizes overall airflow efficiency of the exhaust system in terms of the total fan power required per unit of airflow. It provides an overall measure of how efficiently air is moved through the exhaust system.

Units: W/cfm [$W/l\text{-}s^{-1}$]

V8 = dV9*1000 ÷ dV10
where:
dV9: Exhaust Fan Power (kW)
dV10: Exhaust Fan Airflow (cfm)

See section 8 for more information on the data items.

Benchmarks:

The LBNL cleanroom database does not currently have any data for this metric.

Actions Inferred:

There are two major actions that can be taken to improve airflow efficiency:

- Reduce system pressure drop by removing or changing components.
- Improve fan system efficiency by retrofitting motors, belts, drives.

5. Cooling and Heating Metrics

ID	Name	Priority
T1	Cooling System Efficiency	2
T2	Cooling System Sizing Factor (Installed vs. Peak tons)	2
T3	Chilled Water Loop Temp Differential	2
T4	Heating System Efficiency	2
T5	Reheat Energy Use Factor	1

T1: Cooling System Efficiency

Description:

This metric characterizes the overall efficiency of the cooling system (including chillers, pumps, cooling towers) in terms of energy input per unit of cooling output.

Units: kW/ton [kWe/kWt]

T1 = dT1 ÷ dT2
where:
dT5: Cooling Plant Annual Energy Use (kWh)
dT6: Cooling Plant Annual Load Served (ton-hrs)

See section 8 for more information on the data items.

Benchmarks:

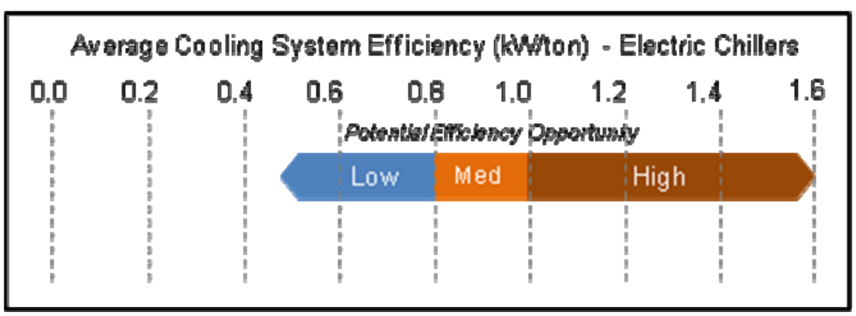

Figure 11. Benchmarks for overall cooling system efficiency for electric chillers

Actions Inferred:

There are many efficiency actions that can be used to improve the overall efficiency of the chiller plant. These include:

- Modularization
- High efficiency chillers
- All-variable-speed system
- Premium efficiency motors

- Increased chilled water temperature
- Water-side economizer
- Controls optimization (staging, resets, etc.)

Special Considerations:

Absorption chillers are typically evaluated using coefficient of performance. The efficiency of absorption chillers should not be compared to electric chillers unless primary energy of fuel inputs is considered.

T2: Cooling System Sizing Factor

Description:

This metric is the ratio of the installed cooling capacity to the peak cooling load.

Units: -

T2 = dT3 ÷ dT4
where:
dT3: Installed Chiller Capacity (w/o backup) (tons)
dT4: Peak Chiller Load (tons)

See section 8 for more information on the data items.

Benchmarks:

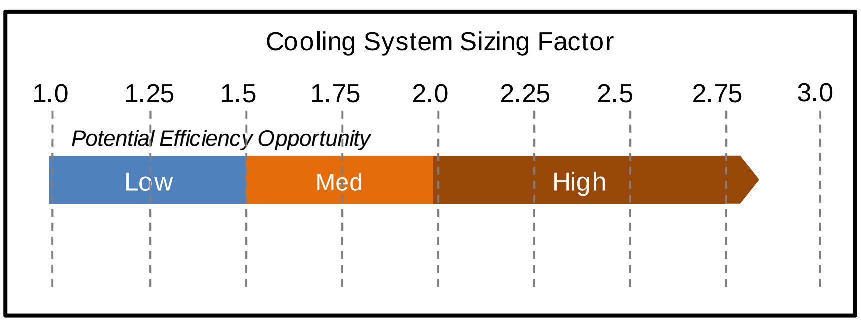

Figure 12. Benchmarks for Cooling System Sizing Factor

Actions Inferred:

A high value for this metric indicates the opportunity to “right-size” the cooling plant and improve part load efficiency. Part load efficiency can also be improved by using a modularized plant design.

T3: Chilled Water Loop Temperature Differential

Description:

This metric is the difference between the chilled water return and supply temperatures.

Units: F [C]

T3 = dT6 – dT5
where:
dT6: Chilled Water Return Temperature (F)
dT5: Chilled Water Supply Temperature (F)

See section 8 for more information on the data items

Benchmarks:

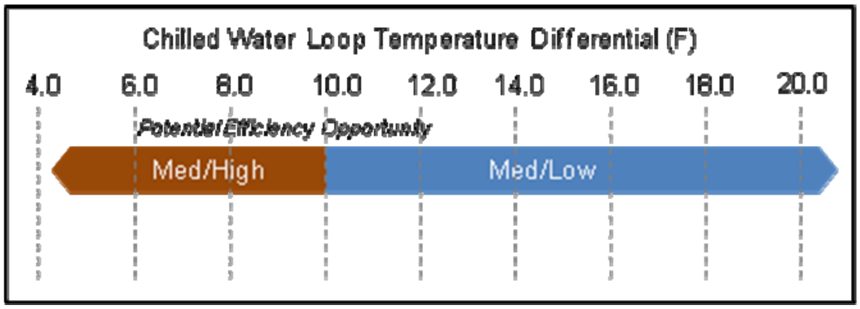

Figure 13. Benchmarks for Chilled Water Loop Temp Differential

Actions Inferred:

A low value for this metric indicates the opportunity to save energy by:

- reducing chilled water flow, and/or
- increasing chilled water supply temperature. (If process cooling is driving the need for low temperatures, consider a separate chiller for process cooling.)

T4: Heating System Efficiency

Description:

This metric characterizes the efficiency of the heating system in terms of energy input per unit of heating output.

Units: %

T4 = dT8 ÷ dT7
where:
dT8: Heating Plant Annual Load Served (MMBTU)
dT7: Heating Plant Annual Energy Use (MMBTU)

See section 8 for more information on the data items.

Benchmarks:

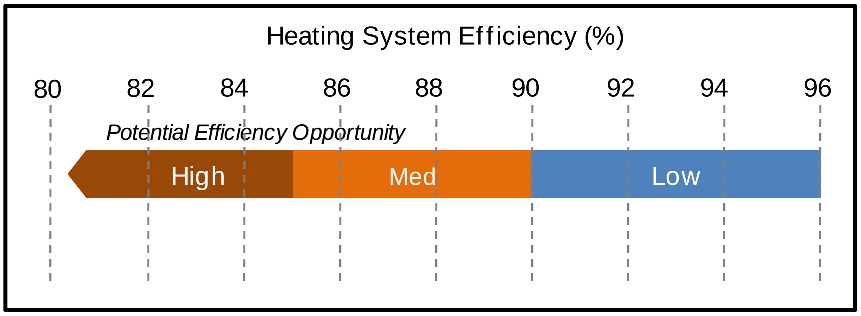

Figure 14. Benchmarks for heating system efficiency

Actions Inferred:

There are many efficiency actions that can be used to improve the overall efficiency of the heating plant. These include:

- Modularization
- High efficiency boilers
- Lower hot water temperature
- Controls optimization (staging, resets, etc.)

T5: Reheat Energy Use Factor

Description:

This metric is the ratio of the reheat energy use to the total heating energy use.

Units: -

T5 = dT9 ÷ dT8
where:
dT9: Reheat Annual Energy Load (MMBTU)
dT8: Heating Plant Annual Load Served (MMBTU)

See section 8 for more information on the data items.

Benchmarks:

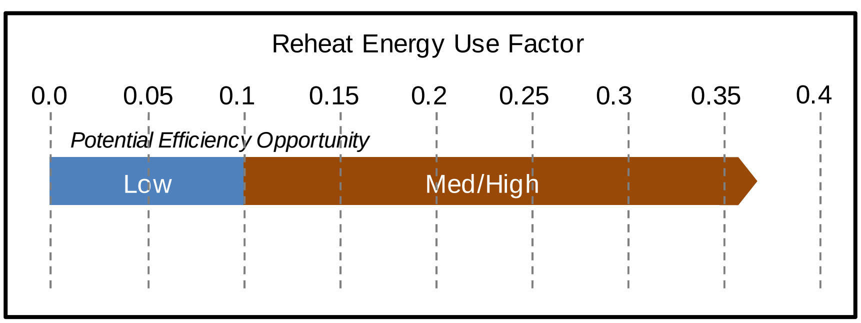

Figure 15. Benchmarks for Reheat Energy Use Factor

Actions Inferred:

Measures to reduce reheat energy use include:

- Widening temperature and humidity setpoint ranges.
- Recalibration and optimization of controls
- Better matching of loads and cooling capacity.

6. Process Load Metrics

ID	Name	Priority
P1	Process Equipment Power Density	2

P1: Process Equipment Power Density

Description:

This metric is the peak process equipment load per unit of cleanroom area.

Units: W/ft^2 $[W/m^2]$

$P1 = dP1*1000 \div dG1$
where:
dP1: Total Process Equipment Power (kW)
dG1: Cleanroom area (net ft^2)

See section 8 for more information on the data items.

Benchmarks:

The data below provide a range of measured values in various types of cleanrooms.

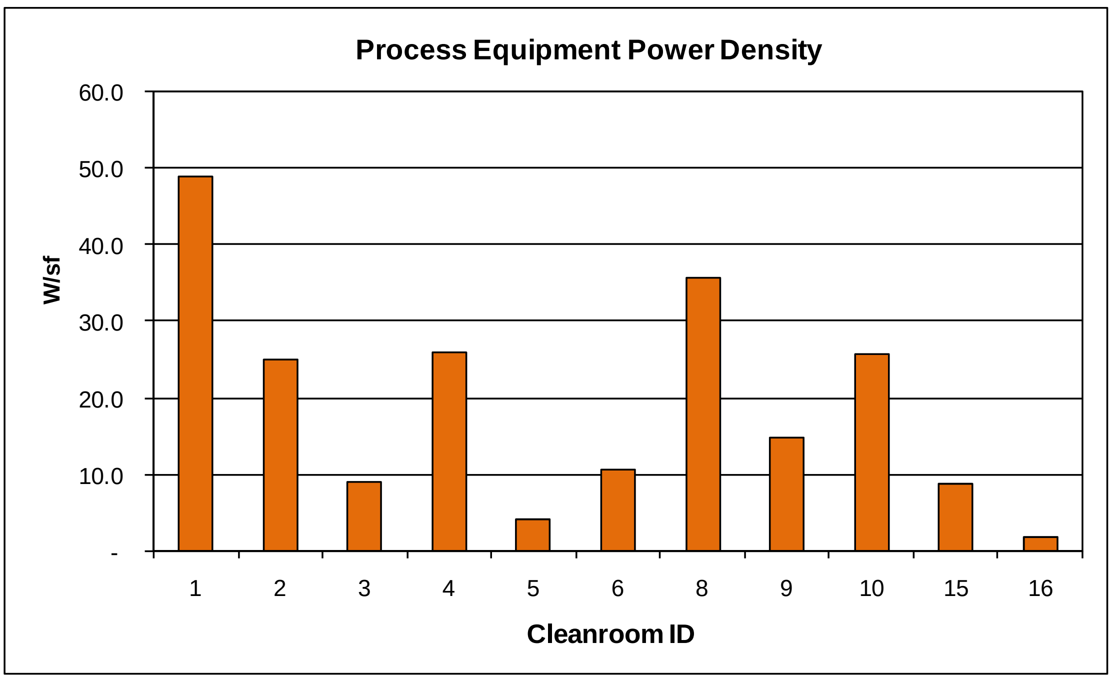

Figure 16. Process equipment power density for cleanrooms in the LBNL database.

Actions Inferred:

Process load is driven by the equipment and processes in the cleanroom. A high value of for this metric may suggest the following actions:

- Conducting a usage audit to identify equipment that may be turned off or retired.
- Procuring more energy efficiency equipment.

Special considerations:

The benchmarks for this metric are driven by the type of processes and equipment in the cleanroom. It is effective only if data for cleanrooms with similar uses are available for comparison.

7. Lighting Metrics

ID	Name	Priority
L1	Lighting Installed Power Intensity	3

L1: Lighting Installed Power Intensity

Description:

This metric is the installed lighting power per unit of cleanroom area.

Units: W/ft^2 [W/m^2]

L1 = dL1*1000 ÷ dG1
where:
dP1: Lighting Installed Power (kW)
dG1: Cleanroom area (net ft^2)

See section 8 for more information on the data items.

Benchmarks:

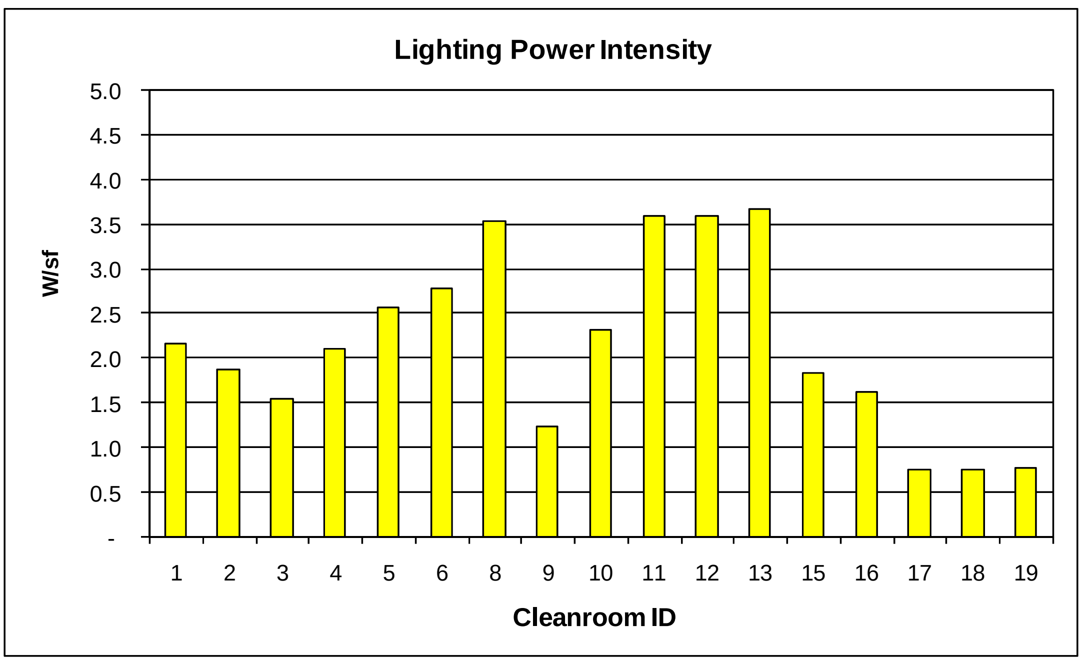

Figure 17. Lighting Installed Power Intensity for cleanrooms in the LBNL database.

Actions Inferred:

A high value for this metric indicates the opportunity to improve the installed lighting efficiency through retrofits including:

- More efficient lamps and ballasts
- More effective fixtures and lighting system configuration.

8. Data Required for Performance Metrics

The table below lists the data required for the performance metrics described in sections 3-7.

ID	Data Item	Measurement/Calculation Guidance
General Facility Data		
dG1	Cleanroom Area	
dG2	Cleanroom Volume	
dG3	Cleanliness level	
Cleanroom Environmental Conditions Data		
dC1	Operating Temperature Range	
dC2	Operating Humidity Range	
dC3	Pressurization	
Ventilation System Data		
dV1	RCU Power	Use design data if measured data not available.
dV2	RCU Airflow	Use design data if measured data not available.
dV3	RCU Total Pressure Drop	Use design data if measured data not available.
dV4	RCU Filter Pressure Drop	Use design data if measured data not available.
dV5	MAU Power	Use design data if measured data not available.
dV6	MAU Airflow	Use design data if measured data not available.
dV7	MAU Total Pressure Drop	Use design data if measured data not available.
dV8	MAU Filter Pressure Drop	Use design data if measured data not available.
dV9	Exhaust Fan Power	Use design data if measured data not available.
dV10	Exhaust Fan Airflow	Use design data if measured data not available.
Cooling & Heating System Data		
dT1	Cooling Plant Annual Energy Use	Includes chillers, pumps, cooling towers.
dT2	Cooling Plant Annual Load Served	If load is not directly measured, it can be calculated from flow rate and supply and return temperatures.
dT3	Installed Chiller Capacity (w/o backup)	Rated capacity.
dT4	Peak Chiller Load	Peak over one year.
dT5	Chilled Water Supply Temperature	Average over 1 year or representative period.
dT6	Chilled Water Return Temperature	Average over 1 year or representative period.
dT7	Heating Plant Annual Energy Use	
dT8	Heating Plant Annual Load Served	If load is not directly measured, it can be calculated from flow rate and supply and return temperatures.
dT9	Reheat Annual Energy Load	Energy used by reheat coils to reheat chilled air.
Process Load Data		
dP1	Total Process Equipment Power	Can be measured at the panel level.
Lighting Data		
dL1	Lighting Installed Power	Can be estimated from lamp specifications.

9. References

Tschudi, W. F. and P. Rumsey. 2004. "Using Benchmarking to Identify Energy Efficiency Opportunities in Cleanrooms: The Labs21 Approach" ASHRAE Symposium.

Xu, T. and W. Tschudi. 2002. "Energy Performance of Cleanroom Environmental Systems." Proceedings of the 48th Annual Technical Meeting and Exposition of the Institute of Environmental Science and Technology (ESTECH), April 28-May 1, 2002, Anaheim, CA. Lawrence Berkeley National Laboratory Report No. LBNL-49106.

Tschudi, W., K. Benschine, S. Fok, and P. Rumsey. 2001. "Cleanroom Energy Benchmarking in High-Tech and Biotech Industries." Proceedings of the 2001 ACEEE Industrial Conference.